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5140-D

STUDENT WORKBOOK

THEATER OF OPERATIONS DRAINAGE

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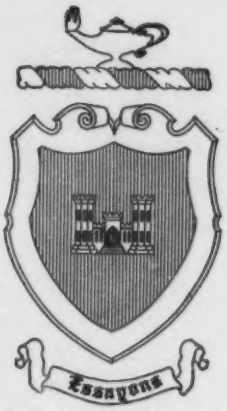

FEBRUARY

1986

US ARMY ENGINEER SCHOOL-FORT BELVOIR, VIRGINIA

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DEPARTMENT OF MILITARY ENGINEERING
US ARMY ENGINEER SCHOOL

THEATER OF OPERATIONS DRAINAGE

ORIENTATION SHEET

SEGMENT	BLOCK	LESSON
Theater of Operations Drainage	5140-D21	ESTIMATION OF RUNOFF
	5140-D21	CONSTRUCTION/ MAINTENANCE CULVERTS AND DITCHES

LESSON: ESTIMATION OF RUNOFF

REFERENCES: FM 5-34 (Sep 1976) as amended by insert "Design and Installation of Expedient Drainage Structures in the Theater of Operations" (Jan 1982)

Programmed Text "Field Expedient Drainage Design" (Feb 1982)

STUDY ASSIGNMENT: Complete the programmed text prior to classroom instruction.

COURSE OUTLINE FOR CLASSROOM INSTRUCTION

A. Introduction to Drainage

1. Why is drainage important?

2. Lesson Objectives:

   a.

   b.

   c.

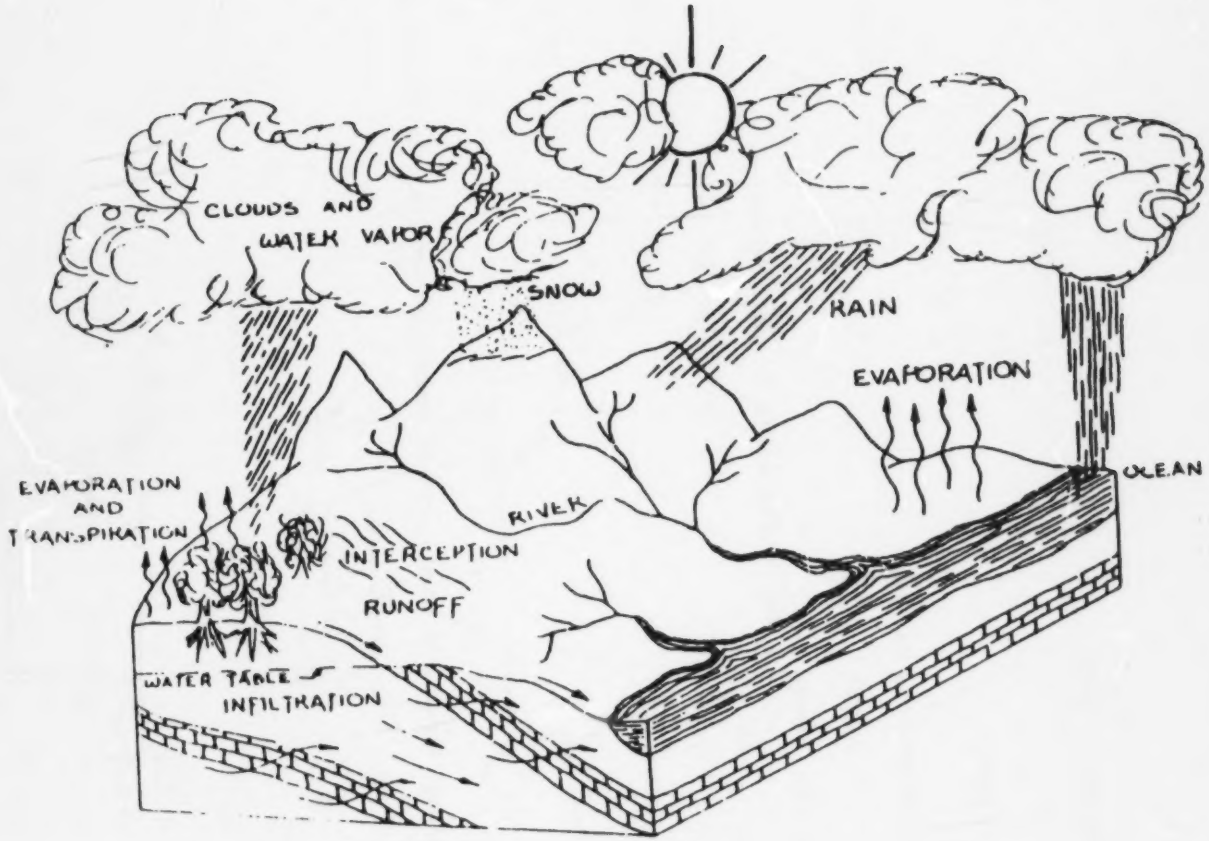
3. Four rules of drainage:

   a.

   b.

   c.

   d.



THE HYDROLOGIC CYCLE

FIGURE 1

4. Phases of project drainage:

   a.

   b.

5. Hydrologic Cycle:

   a. Input:

   b. Response to rainfall:

      (1) Runoff

      (2) Losses

          (a)

          (b)

          (c)

          (d)

          (e)

6. Drainage structures should protect roads (and vertical facilities):

   a. From:

      1.

      2.

      3.

      4.

   b. Utilizing:

      (1)

      (2)

      (3)

      (4)

B. ESTIMATION OF RUNOFF

1. General

a. Two estimation methods (for Q and A_w):

(1)

(2)

b. Definitions :

(1) $Q = VA_w$

(2) A_w

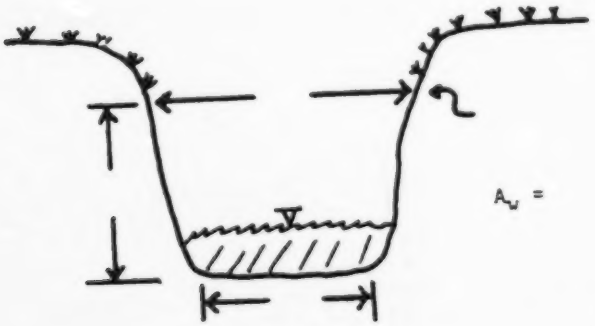
(3) V

(4) Q

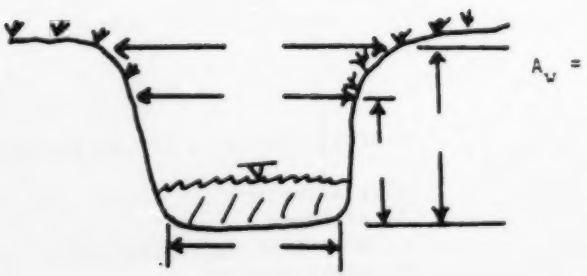
2. Hasty method of determining runoff:

a. Applicability

b. A_w



c. Example:



3. Field estimate (or Q = 2ARC) method of determining runoff:

a. General

(1) A

(2) R

(3) C

(4) Limitations:

(a)

(b)

b. Drainage Area "A":

(1) Delineation

(2) Method of Delineation

(a)
(b)
(c)
(d)

NOTE:

(3) Determine the area of the basin just delineated:

(a) planimeter
(b) stripper
(c) geometric approximation
(d) count squares

c. Rainfall"R"

(1) Intensity

(2) Frequency

(3) Isohyetal (or "R") map: Figure 2, page 7

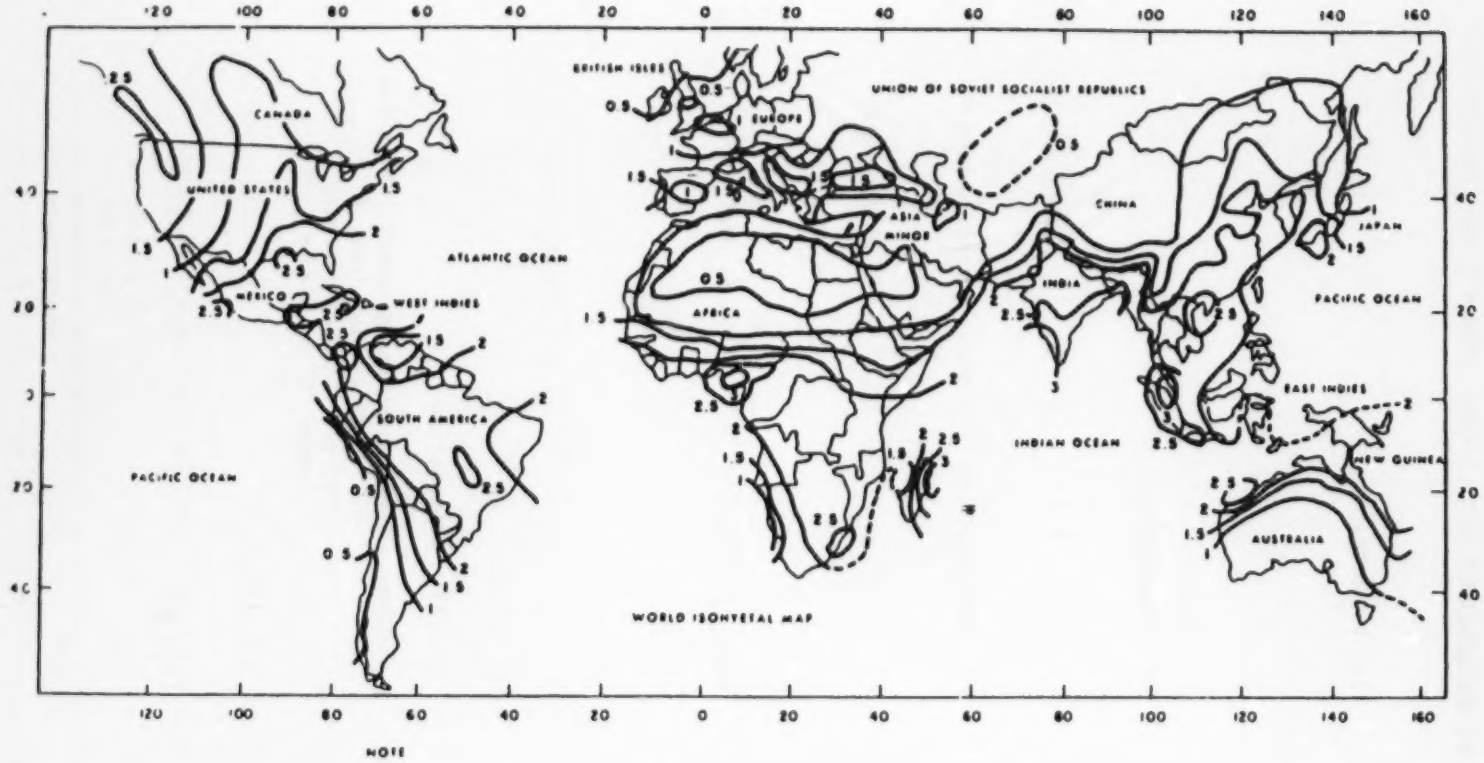
d. Runoff Coefficient "C": Table I, page 8

e. Q = 2ARC Computation

Given: Area contributing runoff = 40 acres
Soil: GMd without turf C =
Location: Giessen, Germany
(under "E" in Europe) R =

Q = 2ARC =

$A_v = \frac{Q}{L}$ =



World isohyetal map.

Figure 2

TABLE I

SOIL DRAINAGE CHARACTERISTICS

USCS - UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS		LETTER		DRAINAGE CHARACTERISTICS	WITH TURF	WITH-OUT TURF
Coarse Grained Soils	Gravel and Gravelly Soils	GW		Pervious	.10	.20
		GP		Pervious	.10	.20
		GM	d	Slightly Pervious	.30	.40
			u	Impervious	.55	.65
		GC		Impervious	.55	.65
	Sand & Sandy Soils	SW		Pervious	.10	.20
		SP		Pervious	.10	.20
		SM	d	Slightly Pervious	.30	.40
			u	Impervious	.55	.65
		SC		Impervious	.55	.65
Fine Grained Soils	Silts and Clays LL < 50	ML		Slightly Pervious	.30	.40
		CL		Impervious	.55	.65
		OL		Impervious	.55	.65
	Silts and Clays LL ≥ 50	MH		Slightly Pervious	.30	.40
		CH		Impervious	.55	.65
		OH		Impervious	.55	.65
Highly Organic Soils		P_t		Slightly Pervious	.30	.40
Man-made Surfaces DO NOT Adjust For Slope	Asphalt pavements, roof surfaces					.95
	Concrete pavements					.90
	Gravel or macadam pavements					.70
Wooded Areas						.20

NOTES:

NOTES:

LESSON: Construction/Maintenance Culverts and Ditches

REFERENCES: FM 5-34 (Sep 1976), as amended by insert "Design and Installation of Expedient Drainage Structures in the Theater of Operations" (Jan 1982)

Programmed Text "Field Expedient Drainage Design" (Feb 1982)

STUDY ASSIGNMENT: Complete the programmed text prior to classroom instruction.

COURSE OUTLINE FOR CLASSROOM INSTRUCTION

A. Culvert Design, Installation, Maintenance

1. General:

a. Types:

(1) Commercial CMP

(2) Nestable CMP

(3) Concrete

(4) Log & Lumber

(5) Other Expedients

2. Construction Considerations:

a. Headwalls and Wingwalls:

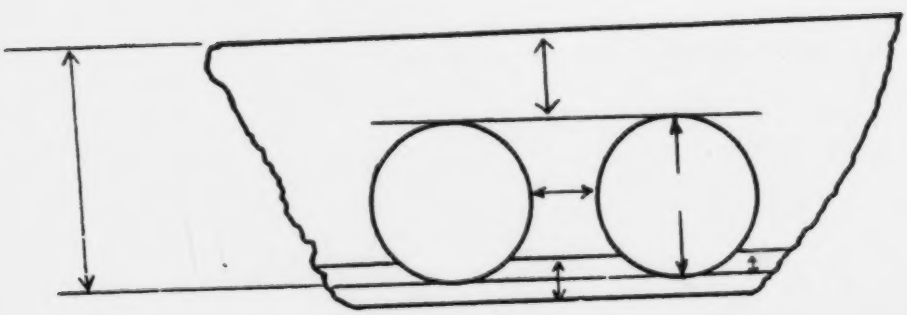
(1) Why use them?

(2) CMP

(3) Concrete

(4) Materials

b. Fill Specifications for Roadway



Strutting

d. Maintenance

e. Alignment

(1) Natural stable channel:

(2) Meandering, unstable channel:

f. Erosion control at outlet

3. Design procedure for CMP culverts

a. A_w, from:

(1)

(2)

(3)

b. A_{des}

c. D_{max}

d. N_p

see design chart on page 15
Table II-A.

e. Length in Place

f. Order Length

TABLE II-A. *Recommended gages for nestable corrugated pipe*

Diam. in inches	Waterway area (sq. ft.)	Fills up to 8 ft.	Fills up to 16 ft.	20-ft. fill	25-ft. fill	30-ft. fill	35-ft. fill	40-ft. fill
8	.35	16	16	16	16	16	16	16
10	.55	16	16	16	16	16	16	16
12 ##	.79	16	16	16	16	16	16	16
15	1.23	16	16	16	16	16	16	16
18 ##	1.77	16	16	16	16	16	16	16
21	2.41	16	16	16	16	16	16	16
24 ##	3.14	16	16	16	16	14	14	14
30 ##	4.91	14	14	14	14	14	12	12
36 ##	7.07	14	14	14	12	12	12	10
42 ##	9.62	14	14	12	12	10	10	8
48 ##	12.57	12	12	12	10	8	8	8
54	15.90	12	12	10	8	8	8	8
60 ##	19.64	12	10	8	8	8	8	8
66	23.76	***	10	8	8	8	8	
72 ##	28.27	***	10	8	8	8	Must be designed for these fill heights and others above 40 ft.	
78	33.18	***	8	8	8			
84	38.49	***	8	8	8			
		***	Insufficient Cover					

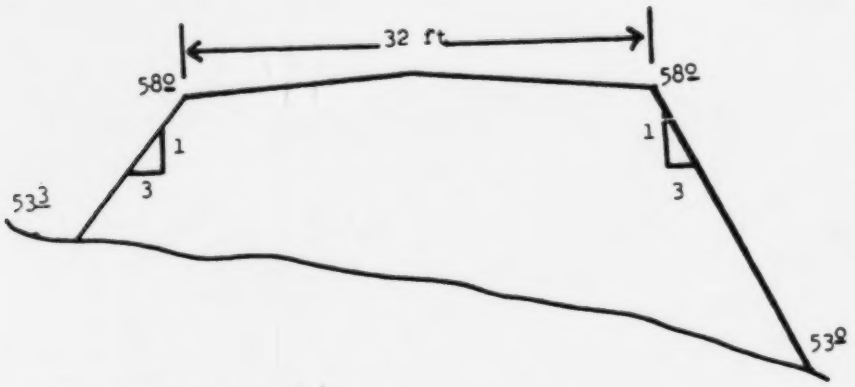
Note. Culverts below heavy line should be strutted during installation.
##Note. Indicates CMP sizes normally found in T/O.

TABLE II-B. *Strut spacing using 4- by 4-inch timbers with compression caps*

Diameter in inches	Length of strut in inches	Fill heights in feet			
		5–10	10–20	20–30	
		Spacing of struts in feet			
48	37.5	6 *	6	6	* NOTE:
54	43.6	6 *	6	6	
60	49.8	6 *	6	6	Ensure
66	56.0	6 *	6	6	sufficient
72	62.2	6 *	6	5	cover!!!

CULVERT DESIGN PRACTICAL EXERCISE

Design the culvert required to pass runoff from Area 1 at Span II Airfield under the class A access road. Area I is composed of 79 acres of GMd soil (well turfed) plus 1 acre of compacted gravel which makes up the roadway. The fill section at the culvert site is shown below. There will be no downstream headwall.



Pipe available at S-4:

Ø	L
18"	1000'
24"	1000'
30"	250'
36"	250'
42"	250'
48"	250'

Design Procedure:

A =

R =

C =

Q =

A_w =

A_{des} =

D_{max} =

N_p =

$N_{36"}$ =

$N_{30"}$ =

Length in Place =

Order Length =

Availability:

Design Solution:

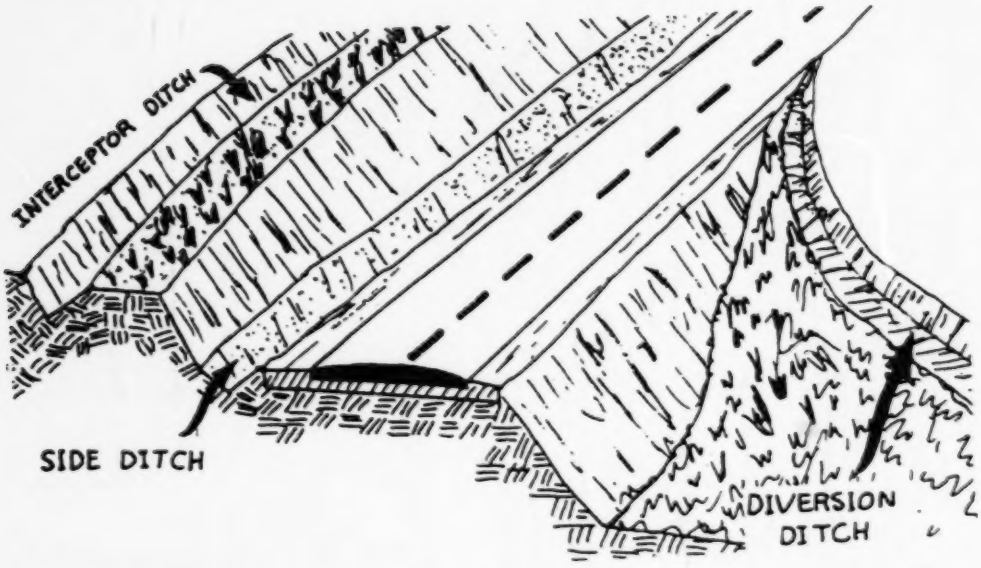
B. DITCH DESIGN, INSTALLATION, MAINTENANCE

1. Three Functional Types

   a.

   b.

   c.



2. Ditch Slopes

   a. Gradient

   b. Side Slopes

      (1) Front Slope

      (2) Back Slope

      (3) Why is 3:1 typically specified for front slopes in side ditches?

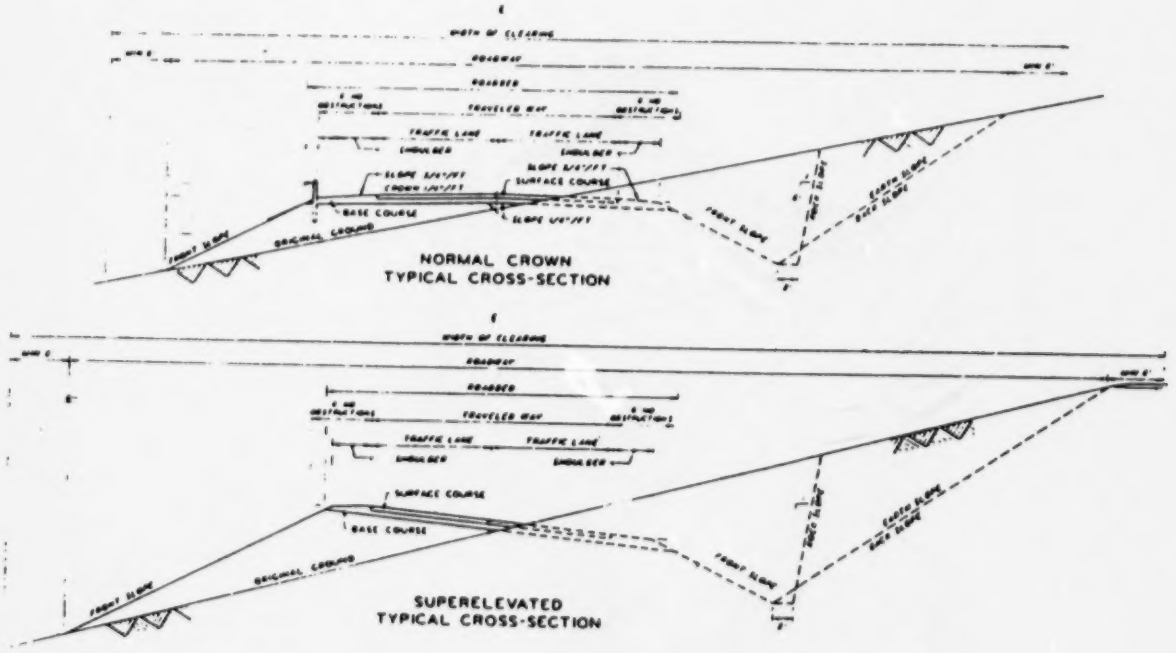


Figure 3.

Typical Crown and Shoulder Slopes for Normal Cross-Sections:

Paved Crown Slope:

Unpaved Crown Slope:

Shoulder Slope:

3. Selection of Ditch Side Slopes:

   a. Shallow ditches in relatively flat terrain:

      (1) Roadside

      (2) Interceptor or Diversion

   b. Deep ditches and/or ditches in hilly terrain:

4. Ditch Geometry:

   a. $Q \leq 60$ cfs

   b. $Q > 60$ cfs

   c. Why?

5. Ditch Design Procedures:

   a. Determine A_w

   b. Select side slope ratios

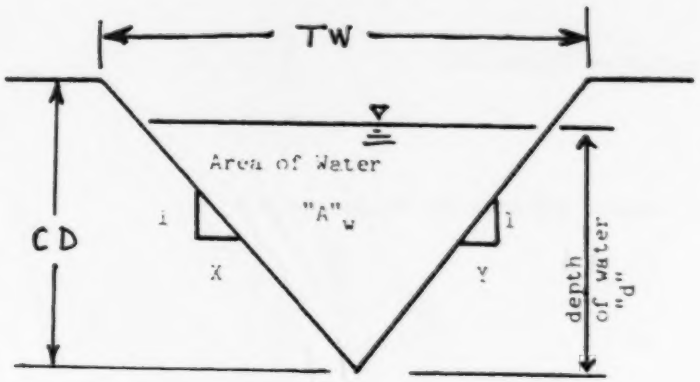
   c. Select ditch shape

   e. Compute cutting depth
      (Add ½ foot freeboard)

   f. Compute top width

   g. Provide a working sketch

6A. Triangular or "V" Ditch Design:



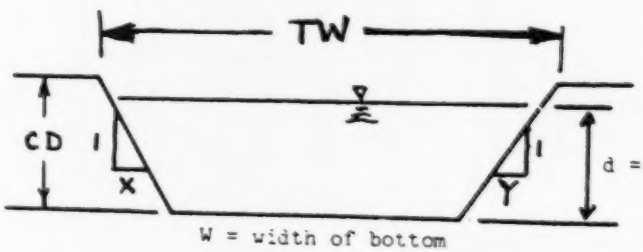
$$d = \sqrt{\frac{2A_w}{X + Y}}$$

a. CD = Cutting Depth = d + ½ foot

b. Top Width (flat terrain) = (X + Y)CD

Top Width (hilly terrain)= (X × CD) + (Y × Height of Backslope)

6B. Trapezoidal Ditch Design:



$$A_w = dW$$

$$d = \frac{A_w}{W}$$

a. CD = Cutting Depth = d + ½ foot

b. Top Width (flat terrain) = (X + Y)CD + W

Top Width (hilly terrain)= (X × CD) + (Y × Height of Backslope) + W

7. Minimum Ditch Depth:

8. Erosion Control:

9. Maintenance:

ROAD CLASSIFICATION

TABLE 1

GEOMETRIC DESIGN POLICIES FOR MILITARY ROADS

DESIGN CONTROLS AND ELEMENTS	CLASS A (2 LANE)	CLASS B (2 LANE)	CLASS C (1 LANE)
DESIGN CONTROLS			
1. TRAFFIC COMPOSITION [1]			
ADT (45% TRUCKS)	935 - 3400	200 - 935	UNDER 200
DHV	140 - 510	30 - 140	UNDER 30
SIGHT DIST RESTRICTION, % [2]	80 - 0	90 - 40	100
2. SPEED			
DESIGN SPEED, MPH	60	40	30
AVERAGE RUNNING SPEED, MPH	45	35	25
CROSS-SECTION ELEMENTS			
3. PAVEMENTS [3]			
MIN WIDTH OF TRAFFIC LANE, FT	12	10	10
LATERAL CLEARANCE FROM EDGE OF TRAFFIC LANE TO OBSTRUCTIONS, FT	6	6	4
NORMAL CROSS-SLOPE, IN./FT	1/4	1/2	1/2
4. SHOULDERS [4]			
MIN WIDTH, FT	4	4	4
NORMAL CROSS-SLOPE, IN./FT	3/4	3/4	3/4
TYPE (PERM ROAD)	STABLE	COMPACTED SOIL	COMPACTED SOIL
5. GUARDRAILS, GUIDEPOSTS, AND EARTH SLOPES [5]	SEE FIGURE 1		
6. BRIDGE CLEARANCE (PERM)	WIDTH OF TRAVELED WAY SHOULD EQUAL TO WIDTH OF LANES PLUS 5 FT (2.5 FT EACH SIDE). 14.75 FT VERTICAL CLEARANCE		
ALIGNMENT ELEMENTS			
7. SIGHT DISTANCE			
MIN STOP SIGHT DIST, FT	475	275	200
MIN PASS SIGHT DIST, FT	2100	1500	N/A
8. HORIZONTAL ALIGNMENT			
MAX HORIZONTAL CURVATURE, DEG [6]	5.5	14.5	26.7
PAVEMENT WIDENING, FT [7]	NONE	2-4	2-5.5
9. VERTICAL ALIGNMENT			
GRADE			
MAX GRADE, %	6	10	15
CRITICAL LENGTH, FT [8]	700	450	250
MIN GRADE, %	0.3	0.3	0.3
VERTICAL CURVES [9]			
CREST VERTICAL CURVE, k, FT	160	55	29
SAG VERTICAL CURVE, k, FT	105	55	35
ABSOLUTE MIN LENGTH, FT	100	120	80

REMARKS

1 THE DESIGN HOURLY VOLUME (DHV) SHOWN FOR ALL ROADS IS IN TOTAL VEHICLES PER HOUR FOR ALL LANES IN BOTH DIRECTIONS. THE DHV IS APPROXIMATELY 15 PERCENT OF THE AVERAGE DAILY TRAFFIC (ADT)

2 THE VALUES SHOWN FOR THIS TERM INDICATE THE COMBINED EFFECTS OF HORIZONTAL (CURVES) AND VERTICAL (GRADE) ALIGNMENT ON CAPACITY. A VALUE OF ZERO PERCENT INDICATES AN ABSOLUTELY STRAIGHT FLAT ALIGNMENT WITH NO RESTRICTION ON SIGHT DISTANCE. A VALUE OF 100 PERCENT INDICATES A ROAD WITH NUMEROUS SHARP CURVES AND GRADE CHANGES ON WHICH THE SIGHT DISTANCE IS LESS THAN 1500 FT AT ANY POINT ON THE ROAD.

3 IF THE ANTICIPATED TRAFFIC INCLUDES A SIGNIFICANT NUMBER OF VEHICLES HAVING WIDTHS IN EXCESS OF 8.5 FT, THE TRAFFIC LANES SHOULD BE WIDENED IN THE AMOUNT BY WHICH THE VEHICLE WIDTH EXCEEDS 8.5 FT.

4 THERE SHOULD BE A COLOR OR TEXTURE CONTRAST BETWEEN TRAFFIC AND SHOULDER SURFACES.

5 WHERE GUARDRAILS OR GUIDEPOSTS ARE REQUIRED, THE SHOULDERS SHOULD BE WIDENED 2 FT

6 VALUES SHOWN ARE CALCULATED ON BASIS OF MAX RATE OF SUPERELEVATION OF 0.1 FT/FT.

7 PAVEMENT WIDENING FOR A CLASS B OR CLASS C ROAD VARIES 2 TO 5.5 FT AS THE CURVATURE VARIES FROM 2 TO 26.7° VALUES OBTAINED MAY BE ROUNDED OFF TO THE NEAREST 0.5 FT.

8 THE TERM "CRITICAL LENGTH" IS USED TO INDICATE THE MAXIMUM LENGTH OF A DESIGNATED UPGRADE UPON WHICH A LOADED TRUCK CAN OPERATE WITHOUT AN UNREASONABLE REDUCTION IN SPEED. CRITICAL LENGTHS MAY BE INCREASED AT AN APPROXIMATE RATE OF 50 FT PER 1 PERCENT DECREASE IN GRADE FROM THE VALUES SHOWN.

9 THE MINIMUM LENGTHS OF VERTICAL CURVES ARE DETERMINED BY MULTIPLYING k BY THE ALGEBRAIC DIFFERENCES IN GRADES (IN PERCENT).

GENERAL NOTES

AS CAN BE SEEN, CAPACITIES ARE SHOWN AS A RANGE OF VALUES. IF MAXIMUM (OR MINIMUM) DESIGN VALUES SHOWN ARE RIGIDLY ADHERED TO, THEN THE RESULTANT CAPACITY OF THE ROAD WILL BE ON THE LOWER SIDE OF THE CAPACITY RANGE. THEREFORE, DISCRETION SHOULD BE USED IN SELECTING DESIGN VALUES BY AVOIDING MAXIMUMS OR MINIMUMS WHENEVER POSSIBLE.

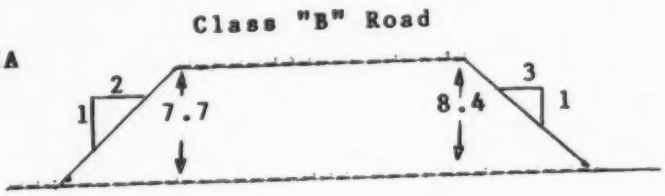
TURNOUTS SHOULD BE PROVIDED AT 1/4-MILE INTERVALS ON CLASS C ROADS.

ALL SHOULDERS SHALL HAVE SIDE SLOPES OF 2:1.

PRACTICAL EXERCISE #1

SITUATION: You are given the job of designing a CMP culvert for the following conditions. Materials are not available to construct a headwall on the downstream side.

A = 48.9
R = Southern INDIA
C = OL w/o turf



Requirement #1: What is the most economical size pipe?

STEP #1: Q =

STEP #2: Aw =

STEP #3: Dmax =

STEP #4: Np =

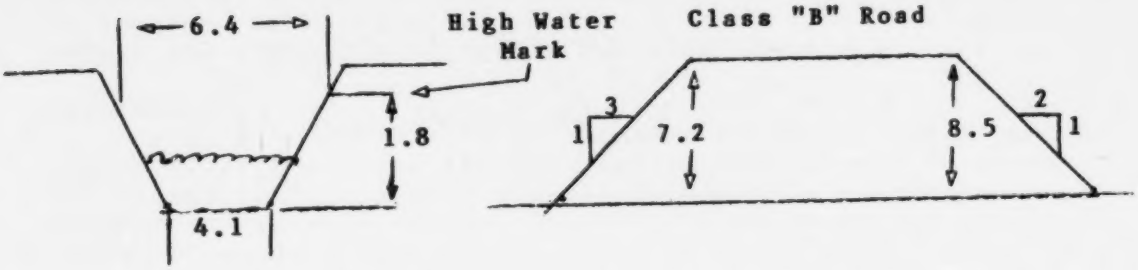
STEP #5: LIP =

Requirement #2: How many feet of CMP will you have to order?

STEP #6: ORDER LENGTH =

PRACTICAL EXERCISE #2

SITUATION: You are given the job of designing a CMP culvert for the following cnditions. Material is not available to construct a headwall on the downstream side.



Requirement #3: How much CMP and what size would you have to order?

STEP #1: Aw =

STEP #2: Adesign =

STEP #3 Dmax =

STEP #4 Np =

STEP #5 LIP =

STEP #6 ORDER LENGTH =

PRACTICAL EXERCISE #3

REQUIREMENT #4

An existing 2 acre airfield cargo storage yard in - southern India will be paved with asphalt. The yard is currently surfaced with compacted gravel. A symetrical "vee" ditch drains the area. The ditch has 3:1 side slopes.

REQUIREMENT:

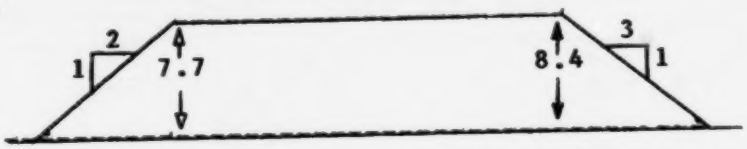
What size ditch will be required to handle the expected runoff after the cargo storage yard is resurfaced? To allow occasional traffic across the ditch, design a symetrical ditch with 3:1 side slopes. Use the 2 year frequency design storm. (Provide a sketch, including all pertinent dimensions needed by your grader operator.)

ANSWER SHEET FOR PE #1

SITUATION: You are given the job of designing a CMP culvert for the following conditions. Materials are not available to construct a headwall on the downstream side.

A = 48.9
R = 3 in/hr
C = .65

Class "B" Road



REQUIREMENT #1: What is the most economical size pipe? 60" pipe

STEP

$Q = 2(48.9)(3)(.65) = 190.7 cfs$

1) $Aw = \frac{Q}{4} = \frac{190.7}{4} = 47.68\ ft^2$

2) $Adesign = 2Aw = 2(47.68) = 95.35\ ft^2$

3) $Dmax = 2/3\ Fmin = 2/3\ (7.7) = 5.13'$ or $61.6"$ ✗ 60"

4) $Np60" \frac{Adesign}{Apipe} = \frac{95.35}{19.64} = 4.8$ ✗ 5 pipes ← USE

$Np48" \frac{Adesign}{Apipe} = \frac{95.35}{12.57} = 7.6$ ✗ 8 pipes

5) $LIP = 2(7.7) + 28 + 3(8.4) + 2 =$
$15.4 + 28 + 25.2 + 2 = 70.6'$ ✗ 72'

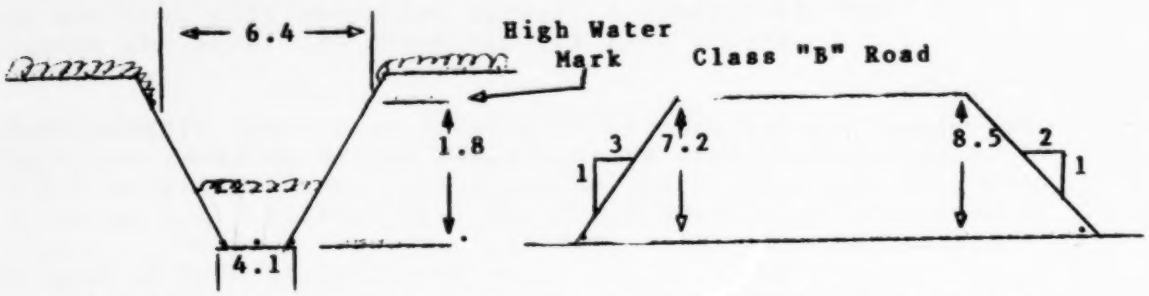
REQUIREMENT #2: How many feet of CMP will you have to order?

6) ORDER LENGTH = Np X LIP X 1.15

= 5 X 72 X 1.15 = 414' OF (CMP) CORRUGATED METAL PIPE.

ANSWER SHEET FOR PE #2

SITUATION: You are given the job of designing a CMP for the following conditions. Material is not available to construct a headwall on the downstream side.



REQUIREMENT #3: How much CMP and what size would you have to order?

STEP

1) $Aw = \frac{(6.4 + 4.1)}{2}\ 1.8 = 9.45\ ft^2$

2) $Adesign = 2(9.45) = 18.9\ ft^2$

3) $Dmax = 2/3\ (7.2)\ (12) = 57.6"$ ∅ 48"

4) $Np48" \quad \frac{Adesign}{Apipe} = \frac{18.9}{12.57} = 1.5$ ∅ 2 pipes

$Np42" \quad \frac{18.9}{9.62} = 1.96$ ∅ 2 pipes ⟵ USE

$Np36" \quad \frac{18.9}{7.07} = 2.7$ ∅ 3 pipes

5) $LIP = 3(7.2) + 28 + 2(8.5) + 2 =$

$21.6 + 28 + 17 + 2 = 68.6'$ ∅ 70′

6) ORDER LENGTH = NP X LIP X 1.15

= 2 X 70 X 1.15 = 161′ ∅ 162′ OF CMP

ANSWER SHEET FOR PE #3

REQUIREMENT #4:

An existing 2 acre airfield cargo storage yard in southern India will be paved with asphalt. The yard is currently surfaced with compacted gravel. A symetrical "vee" ditch drains the area. The ditch has 3:1 side slopes.

REQUIREMENT: What size ditch will be required to handle the expected ruoff after the cargo storage yard is resurfaced? To allow occasional traffic across the ditch, design a symetrical ditch with 3:1 side slopes. Use the 2 year frequency design storm. (Provide a sketch, including all pertinent dimension needed by your grader operator.)

NEW Q

$Q = 2ARC$

WHERE A = 2 acres
R = 3.0 in/hr (southern India)
C = .95 (asphalt)

$Q = 2(2)(3.0)(.95) = 11.4$ cfs

$$Aw = \frac{11.4 \text{ cfs}}{4 \text{ fps}} = 2.85 \text{ ft}^2$$

CONTINUATION ON NEXT PAGE

ANSWER SHEET FOR PE #3 CONTINUED

COMPARE:

2.85 > 0.75 Design a new symmetrical ditch with 3:1 slopes.

NEW DITCH:

$$d = \sqrt{\frac{2\ (2.85)}{3 + 3}} = .97 \approx 1.0'$$

CD = 1.0 + 0.5 = 1.5'

TW = 1.5(3 + 3) = 9'